Using Beam Normal Asymmetry in QWeak to Access the Elastic Form factors of the Delta(1232)

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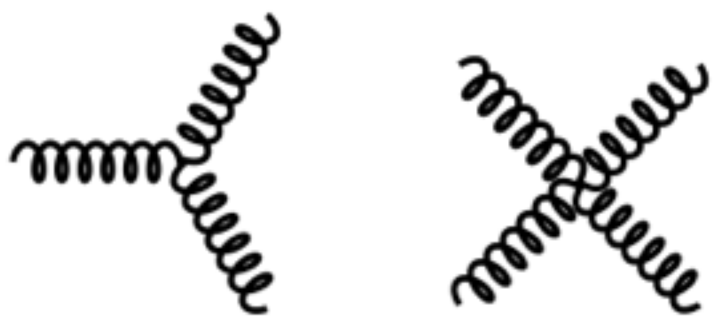
A SEARCH FOR NEW PHYSICS

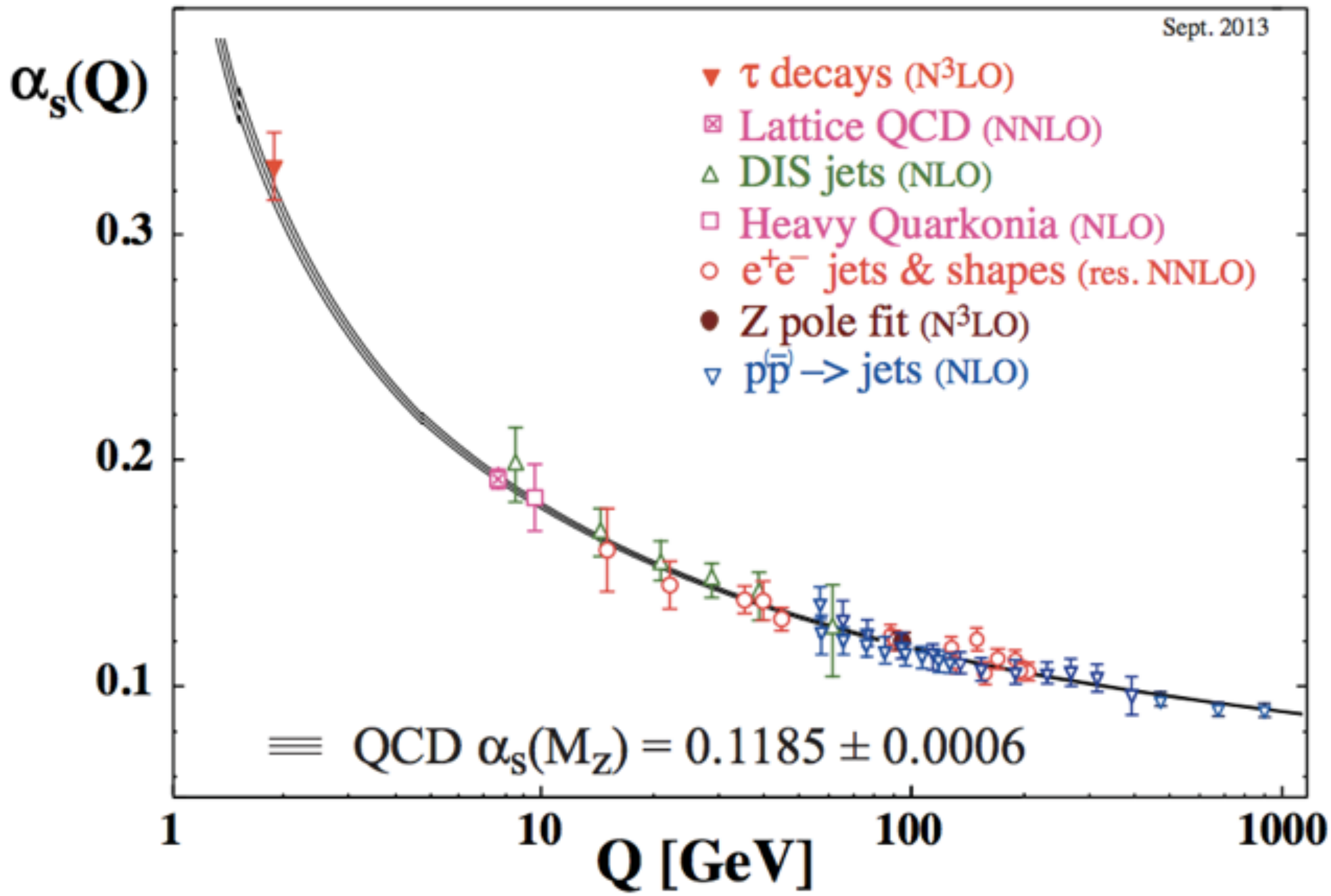
Qweak

Quantum Chromodynamics (QCD)

strong interaction is responsible for most of the visible mass

gluon-gluon interactions





weak at high energies but very strong at scales appropriate for life

confinement of quarks

How do we study the strong coupling regime of QCD?

Motivation

Spectroscopy

Study of the properties of states of QCD: production mechanisms, mass, width, quantum numbers and decay modes (and form-factors.)

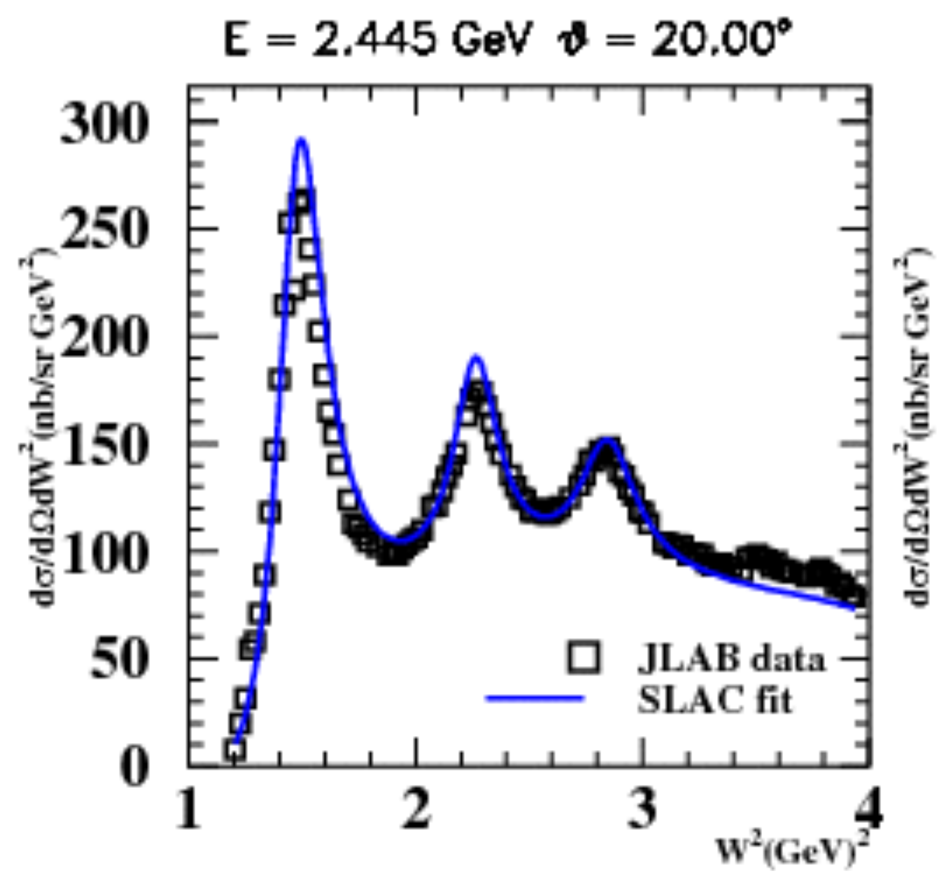
Major success: quark model itself grew out of such studies.

The Δ resonance

- lowest lying nucleon excitation;
- experimentally well separated;
- very short lived

Form Factors

Form Factors contain information on the positions of charges within a hadron (infinite momentum frame: form factor is 2D Fourier transform of transverse density.)



Δ Elastic Form Factors (γ*ΔΔ)

There are 4 elastic form factors (spin-3/2)

$$G_{E_0}(Q^2),\ G_{M_1}(Q^2),\ G_{E_2}(Q^2),\ \&\ G_{M_3}(Q^2)$$

associated with distribution of charge, magnetization and non-spherical deformations

$$G_{E_0}(0) = e_\Delta$$ Charge

$$G_{M_1}(0) \propto \mu_\Delta$$ Magnetic moment

$$G_{E_2}(0) \propto D_\Delta$$ Dipole moment

$$G_{M_3}(0) \propto O_\Delta$$ Octopole moment

PDG $$\frac{\mu_{\Delta^+}}{\mu_N} = 2.7^{+1.0}_{-1.3} \pm 1.5 \pm 3$$ (stat, syst, theory)

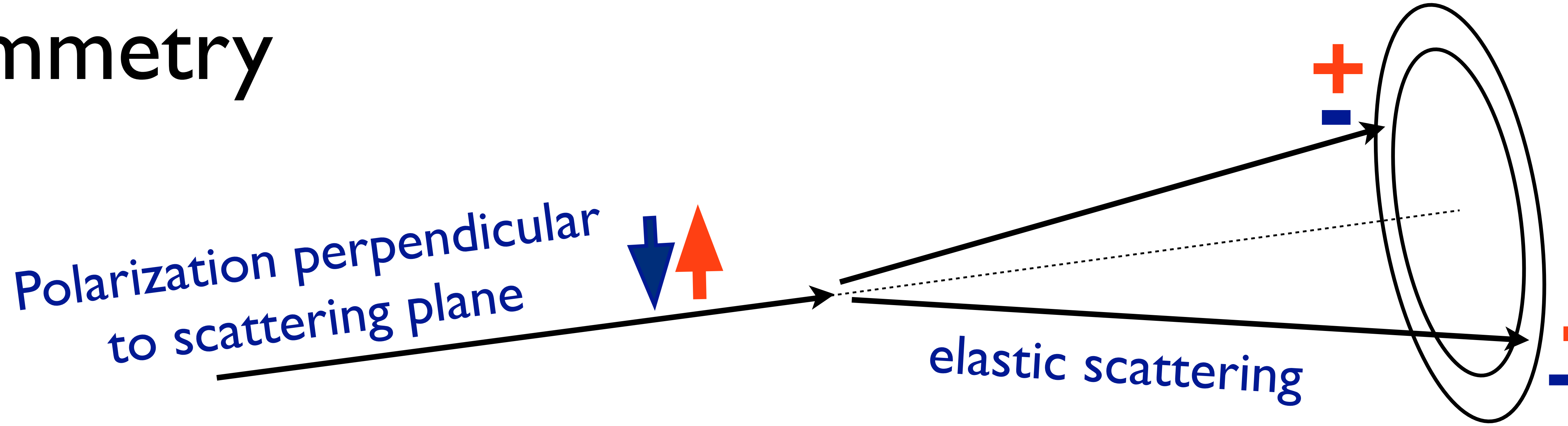
Tapps & Mainz $\gamma p \to p\pi^0\gamma'$

no direct measurements of dipole and octopole moments

$$Q_{p\to\Delta^+} = -(0.0846 \pm 0.0033)\ \mathrm{e\ fm^2}$$

can potentially extract elastic information

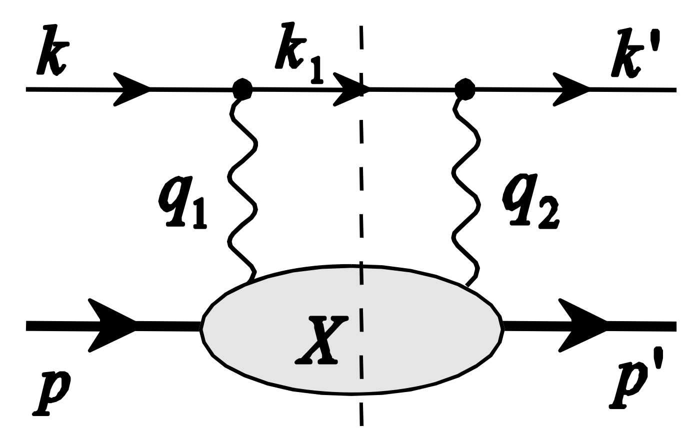
B_n asymmetry



time-reversal invariance forces this SSA to vanish for one-photon exchange

arises from an interference between the one-photon exchange (Born) amplitude and the imaginary part of the two-photon exchange amplitude

$$B_n = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{2\mathrm{Im}(T_{2\gamma} \cdot T^*_{1\gamma})}{|T_{1\gamma}|}$$



intermediate states on-shell

Asymmetry is very small

$$B_n \sim \alpha_{\mathrm{em}} \frac{m_e}{E_e} \sim 10^{-6} - 10^{-5}$$

2-photon

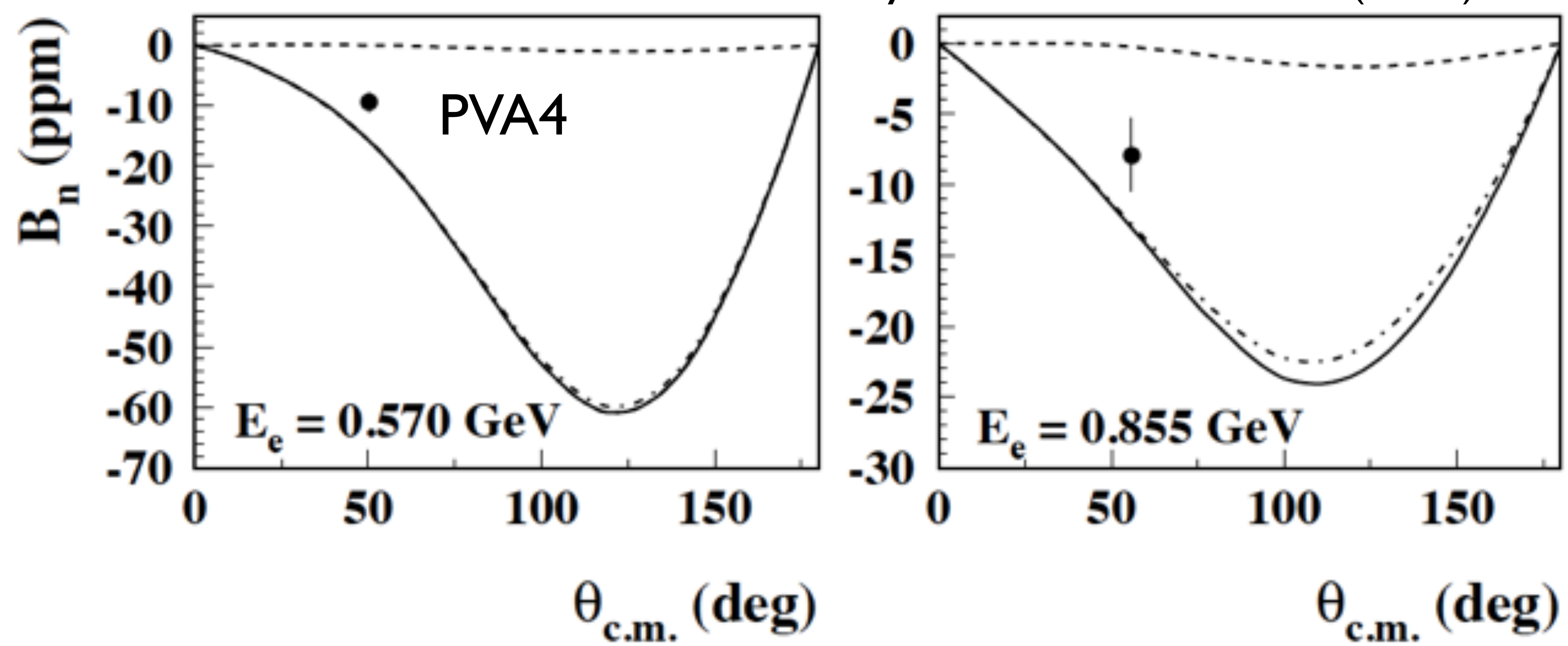
ultra-relativistic

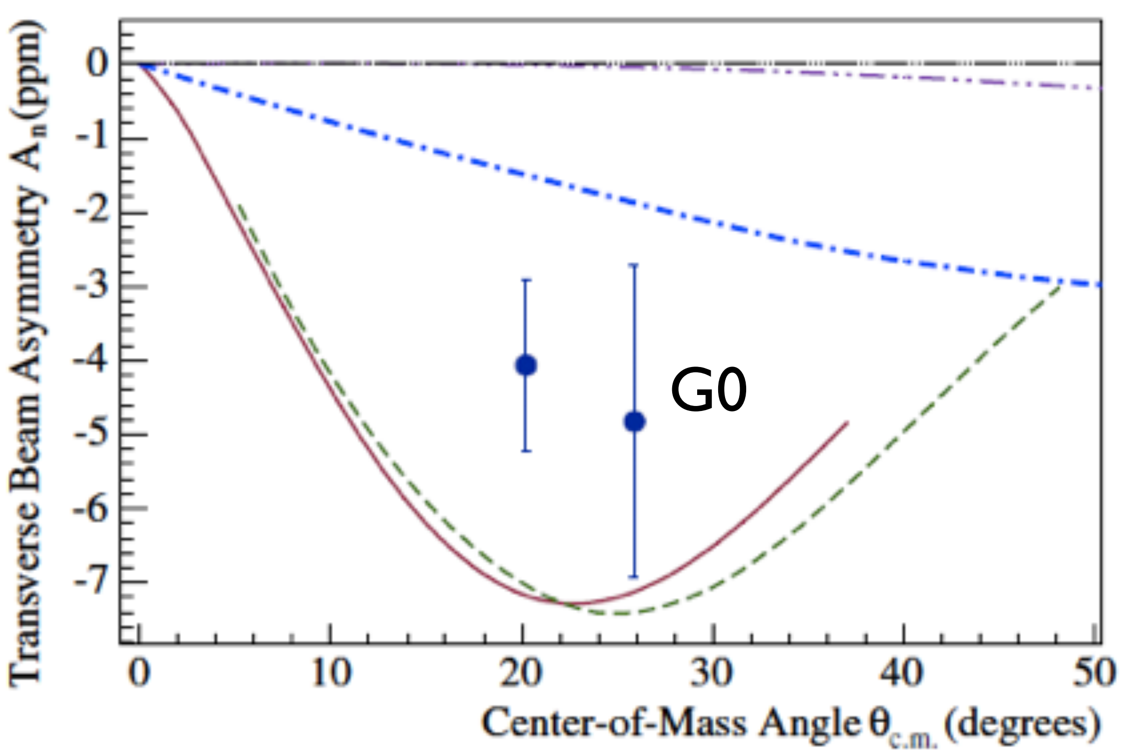
B_n asymmetry in ep elastic

Calculations reasonably well under control - generally reproduce the data to better than a few σ

Require excited intermediate states

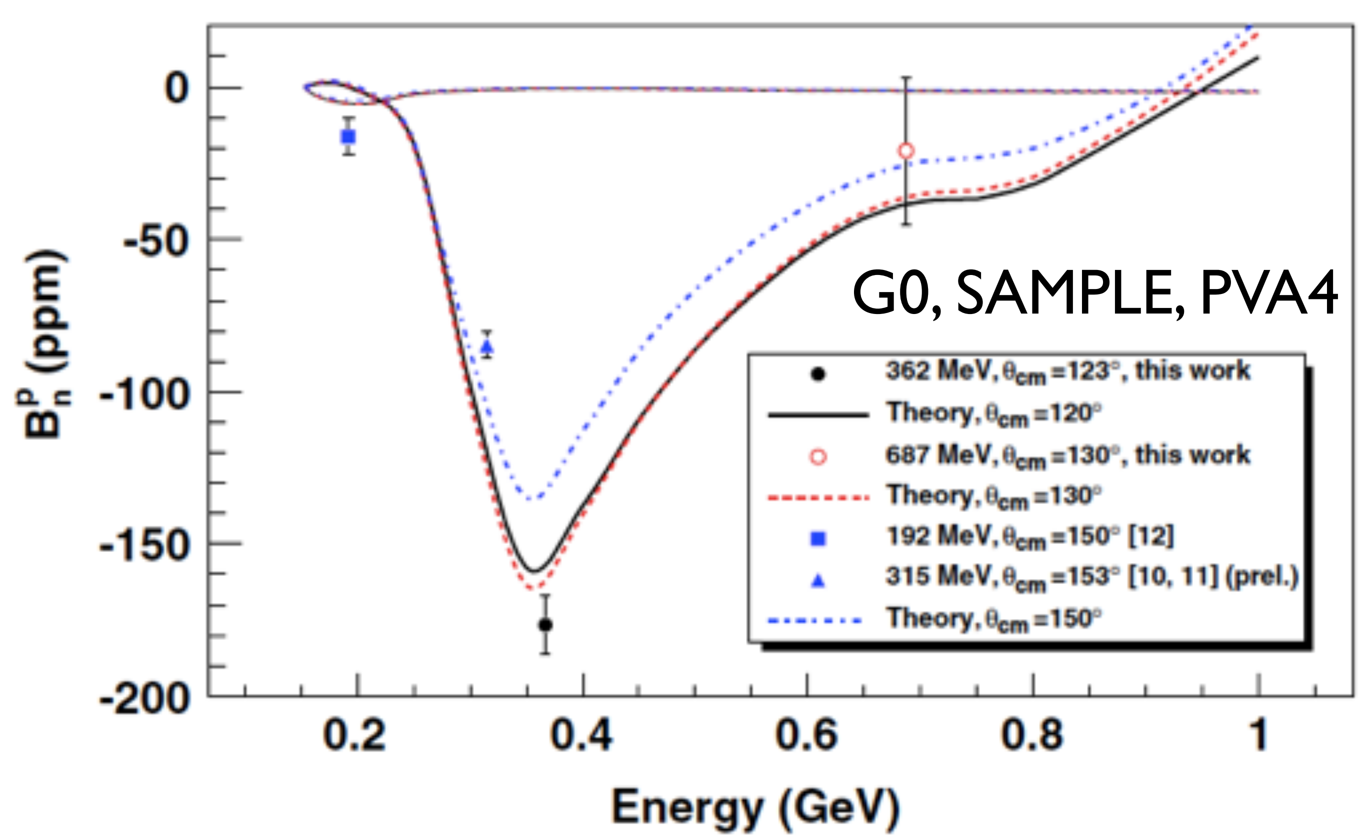
Phys.Rev.Lett. 94, 082001 (2005)





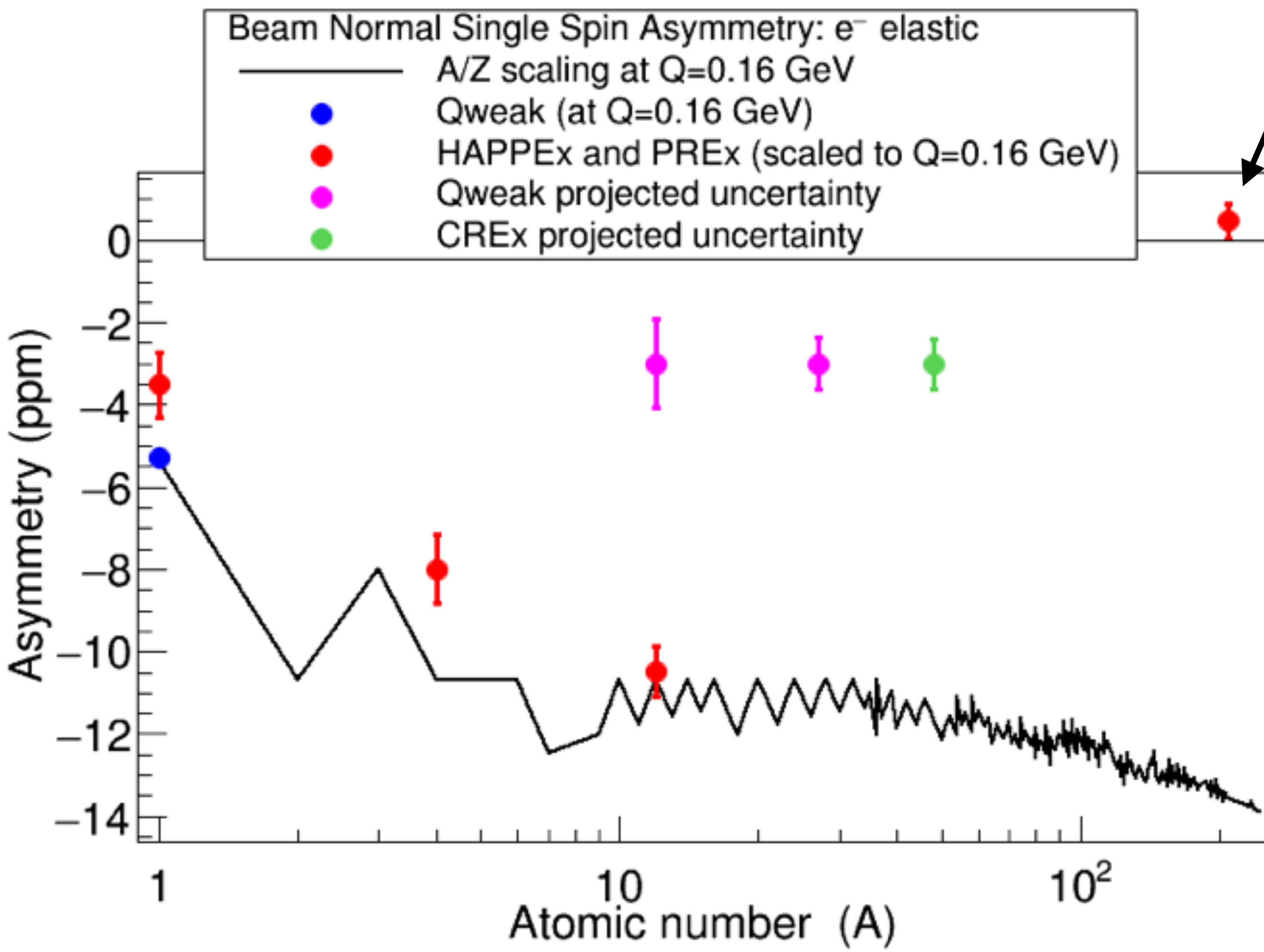
Phys.Rev.Lett. 99 (2007) 092301

Phys.Rev.Lett. 107 (2011) 022501



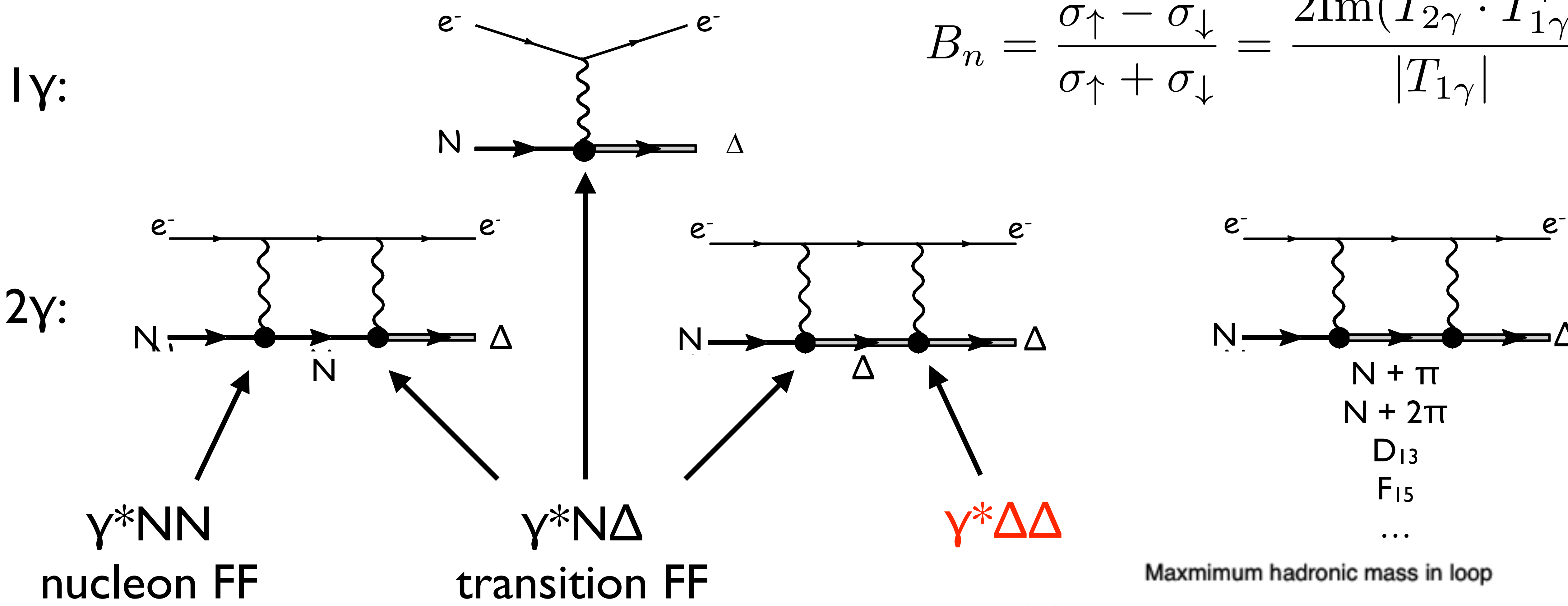
B_n asymmetry in nuclear elastic

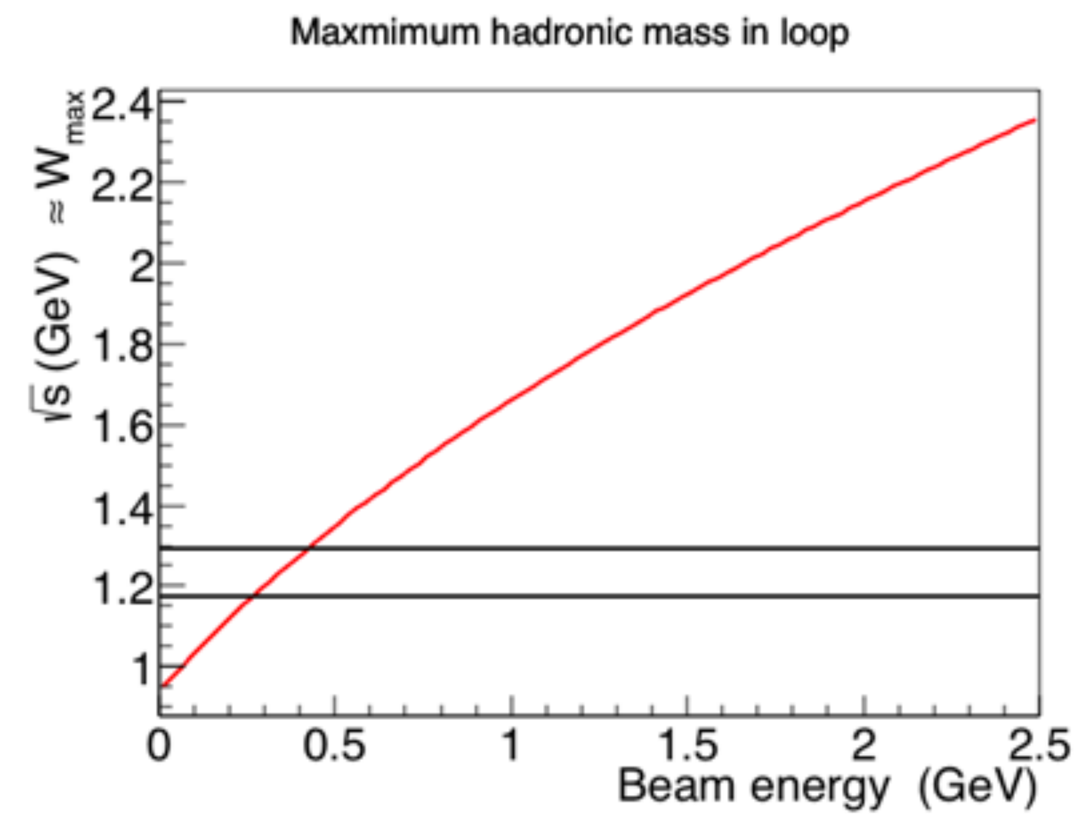
Calculations of B_n asymmetry in forward-angle elastic scattering match nuclear data except for the heaviest nuclei (assumed due to Coulomb distortion.)



Asymmetry calculations for Δ production

$$B_n = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{2\mathrm{Im}(T_{2\gamma} \cdot T^*_{1\gamma})}{|T_{1\gamma}|}$$



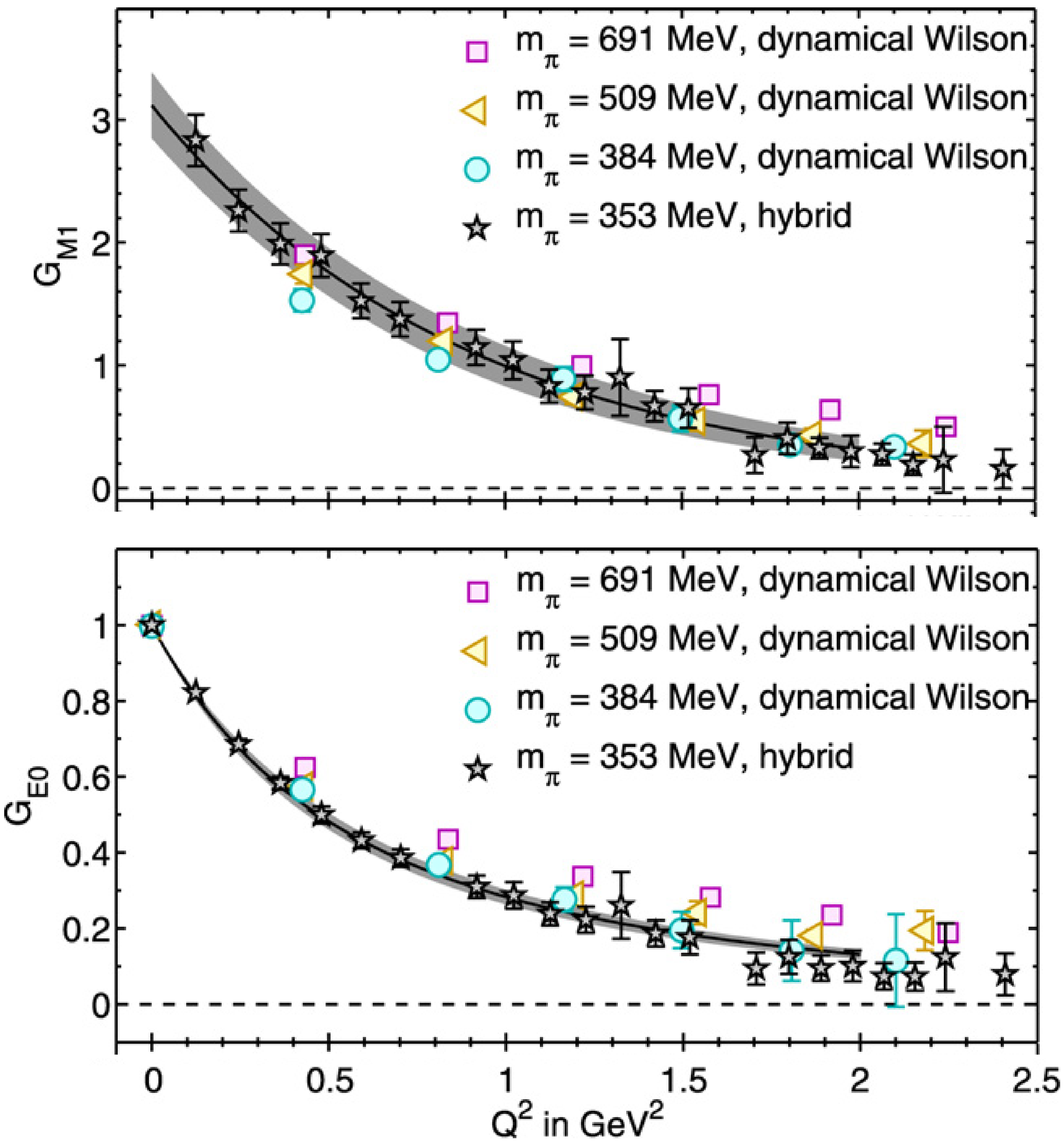


Some disagreement in the elastic scattering case (suspected missing intermediate states)

Treatment of additional intermediates states is difficult (transition to Δ)

Higher beam energies allow more intermediate states

Lattice Calculation of γ*ΔΔ

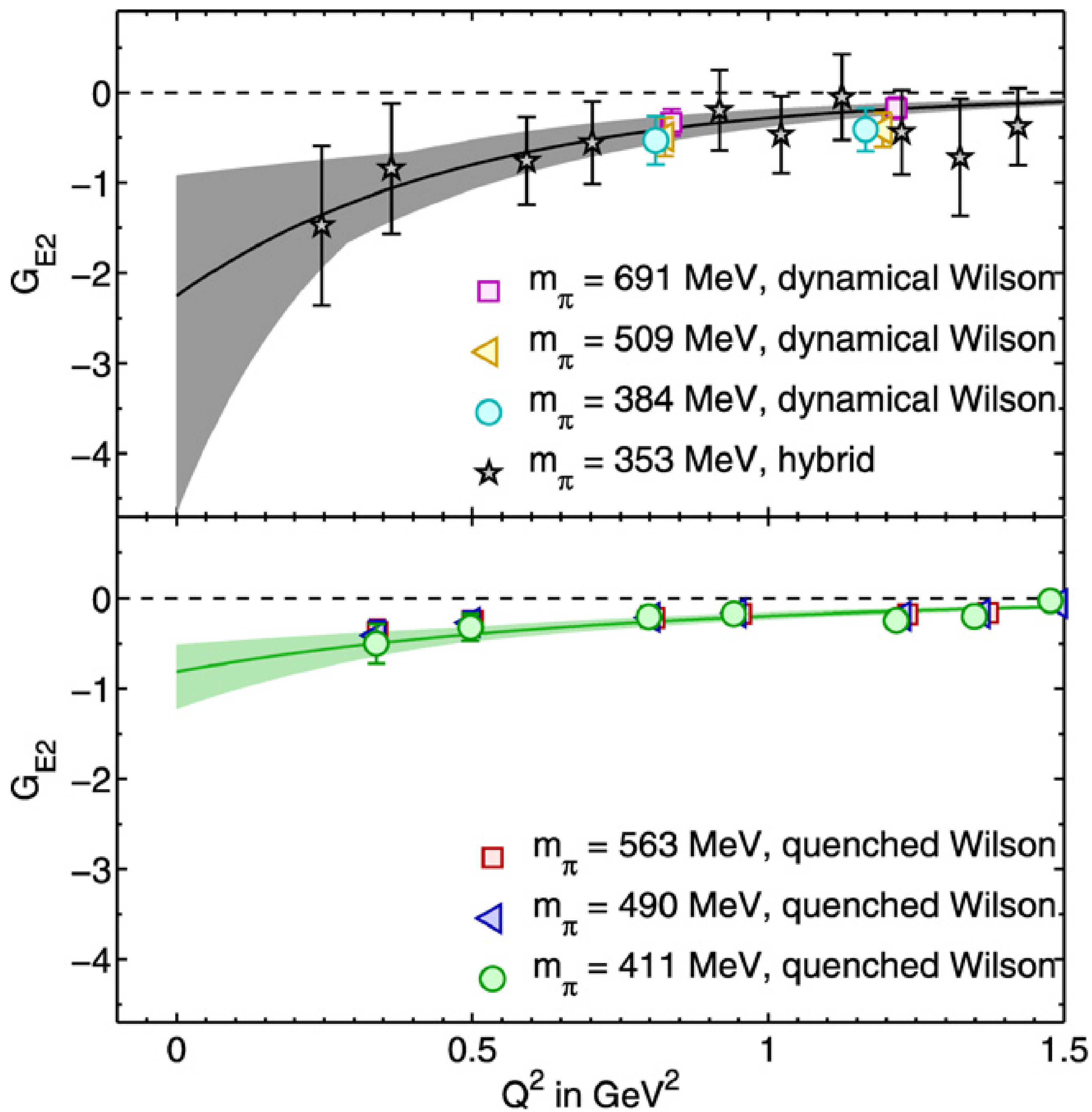


The γΔΔ form factor is obtain from lattice calculations with a stable Δ assuming that the disconnected diagrams are small

Δ stable at these pion masses

C. Alexandrou et al.
Nuclear Physics A 825 (2009) 115–144

Lattice Calculation of γ*ΔΔ



Factor of 2 difference in lattice results for quadrupole quenched or dynamical.

Octopole has large uncertainties, consistent with 0

C. Alexandrou et al.
Nuclear Physics A 825 (2009) 115–144

Parametrization of γΔΔ form factors

$$G_{E_0}(Q^2) = \frac{1}{(1 + Q^2/\Lambda^2_{E_0})^2}$$

$$G_{M_1}(Q^2) = G_{M_1}(0)e^{-Q^2/\Lambda^2_{M_1}}$$

$$G_{E_2}(Q^2) = G_{E_2}(0)e^{-Q^2/\Lambda^2_{E_2}}$$

$$G_{M_3}(Q^2) = 0$$

This parametrization fitted to lattice calculations and used in B_n calculation.

$$G_{E_0}(Q^2) = 1 - \frac{1}{6}R^2_\Delta Q^2 + \ldots$$

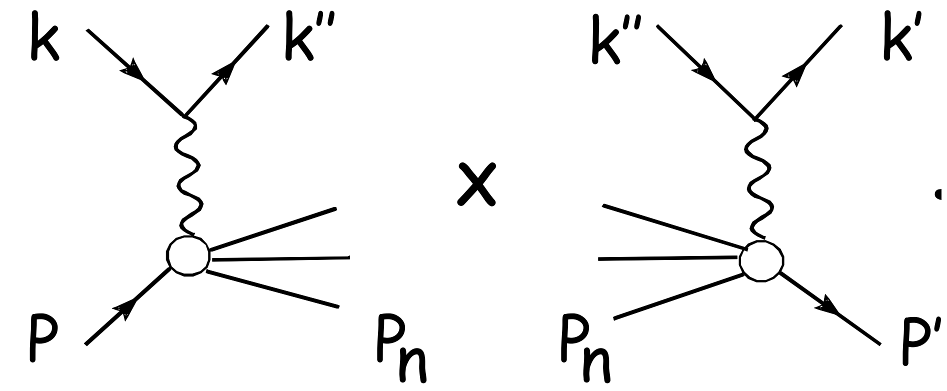
Alternate parametrization

How sensitive are calculations of the beam asymmetry to changes in:

- parametrization of form-factors?
- parameters such as charge radius, magnetic moment, quadrupole moment, … ?

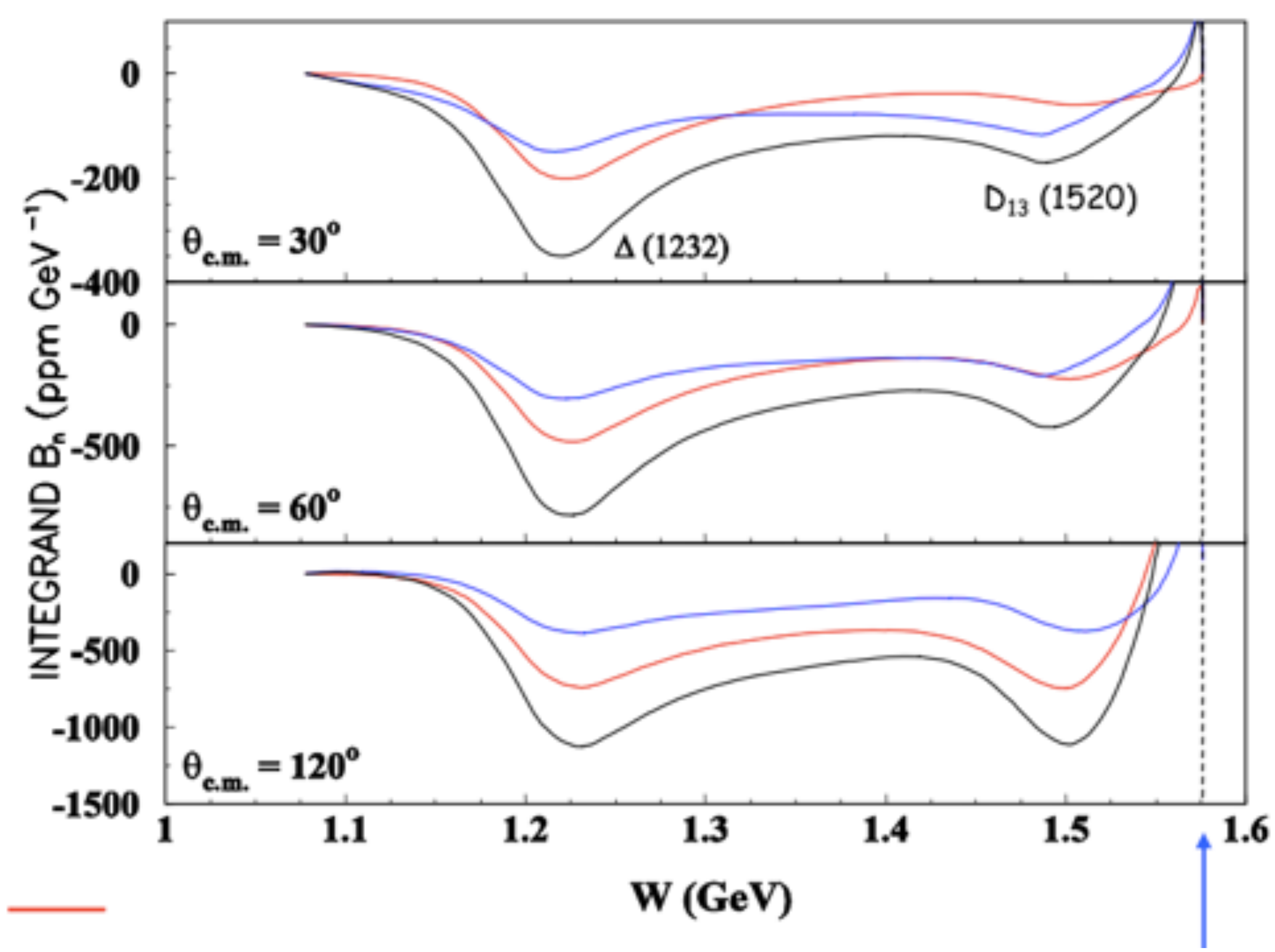
Calculation dependence on beam energy

Example from calculation for elastic scattering
Higher beam energy increases maximum intermediate hadronic mass

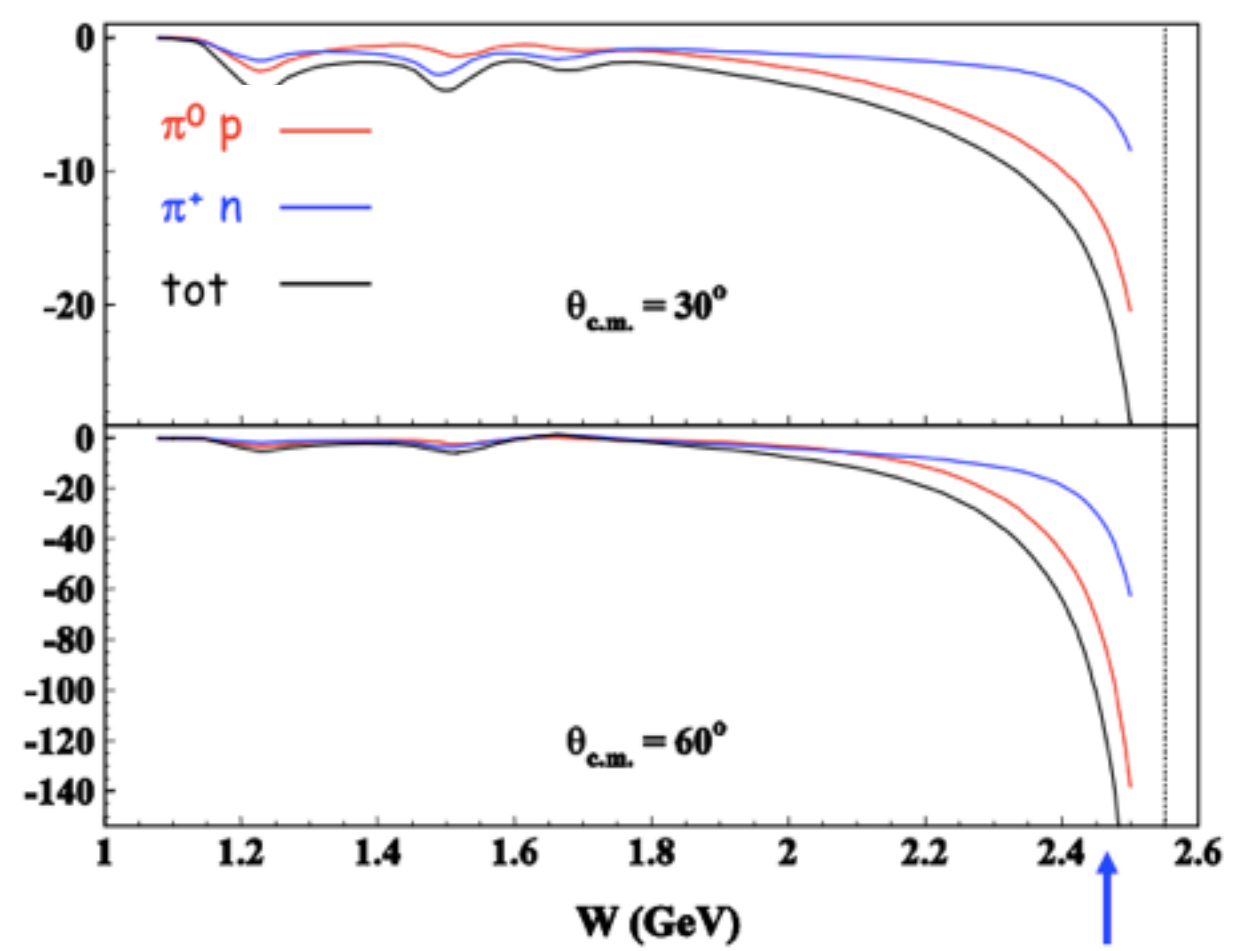


on-shell intermediate states

0.855 GeV



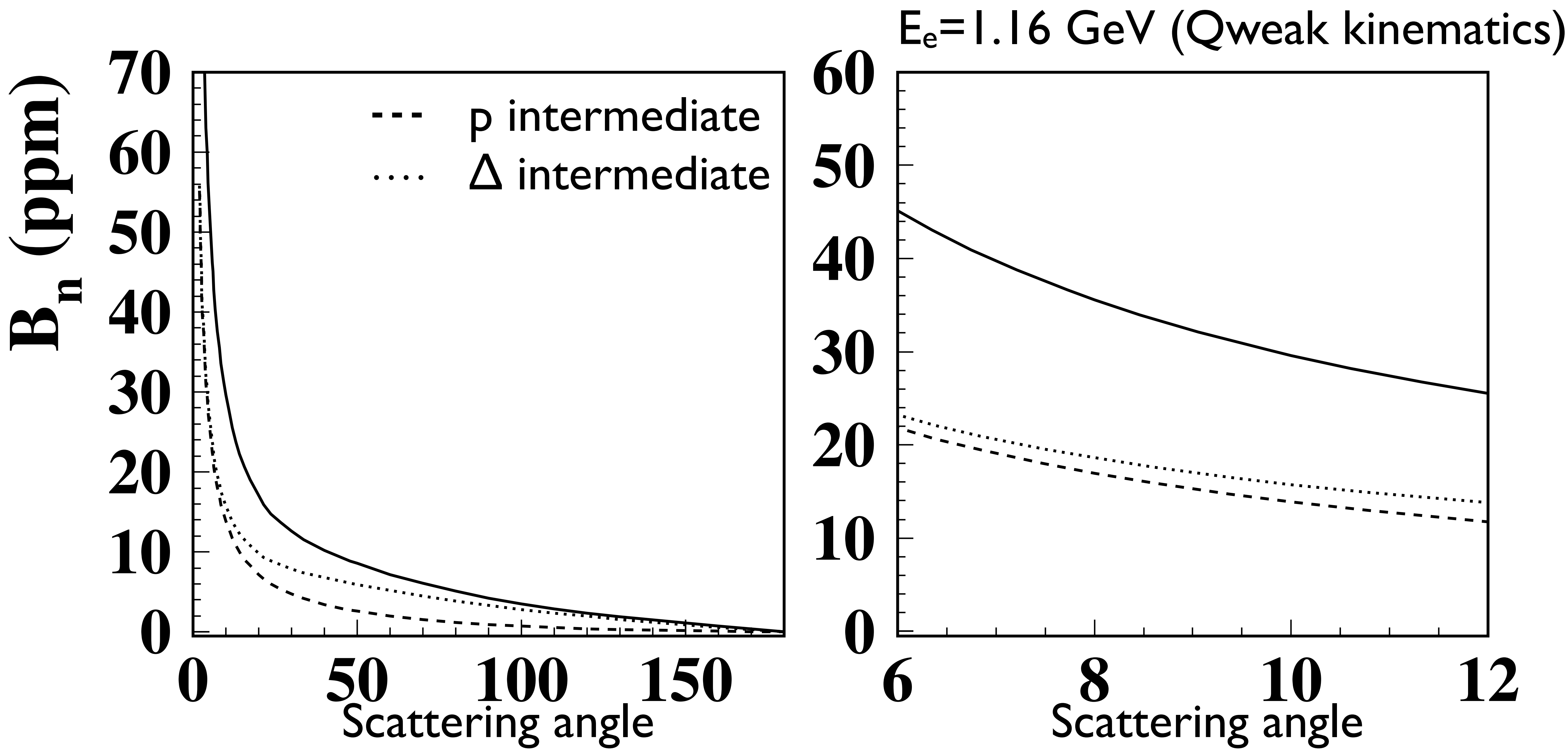
3 GeV



PRC 70, 045206 (2004) Pasquini & Vanderhaeghen

B_n asymmetry calculation

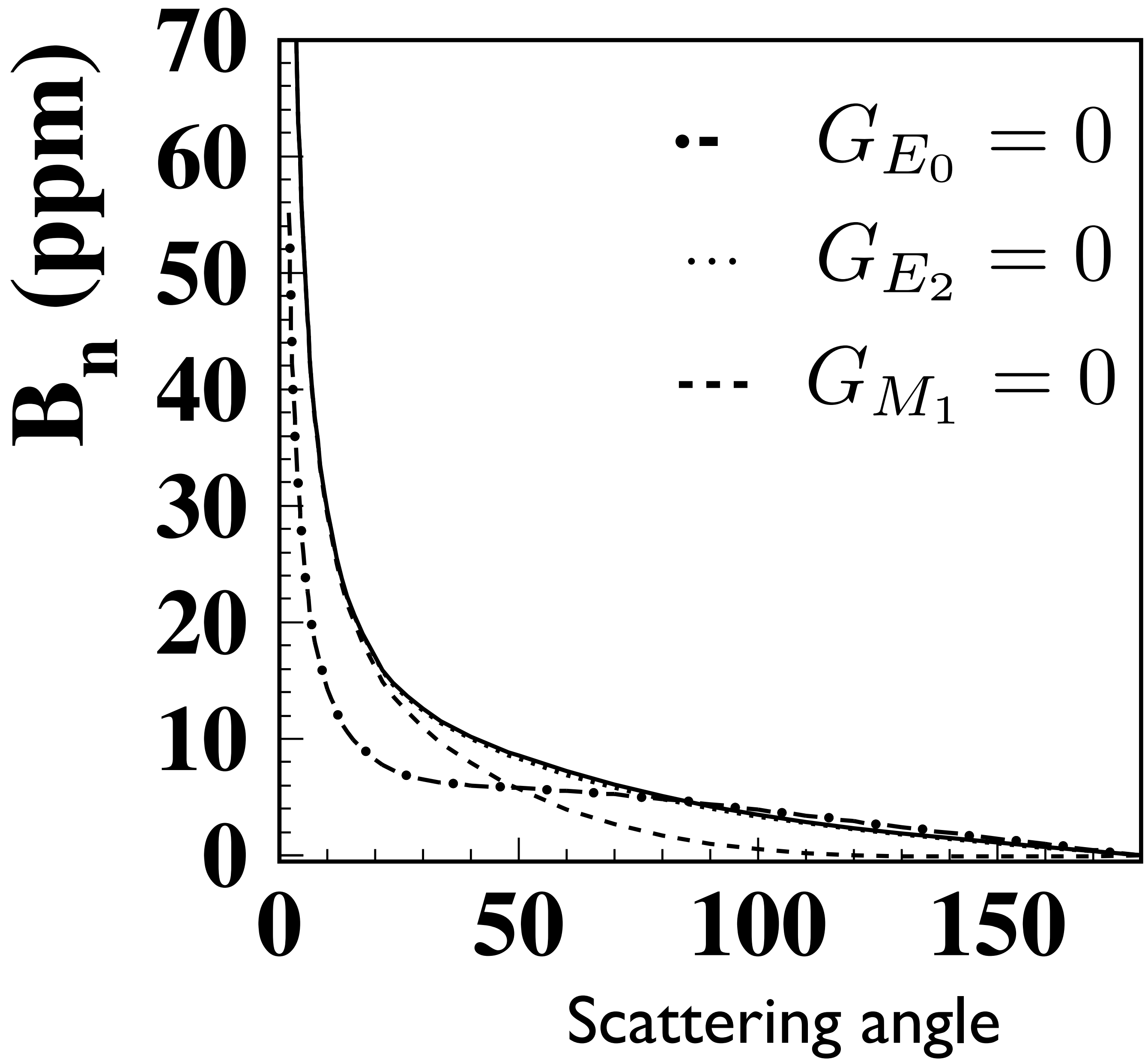
Asymmetry highest in forward direction where rates are highest, attractive for measurement.

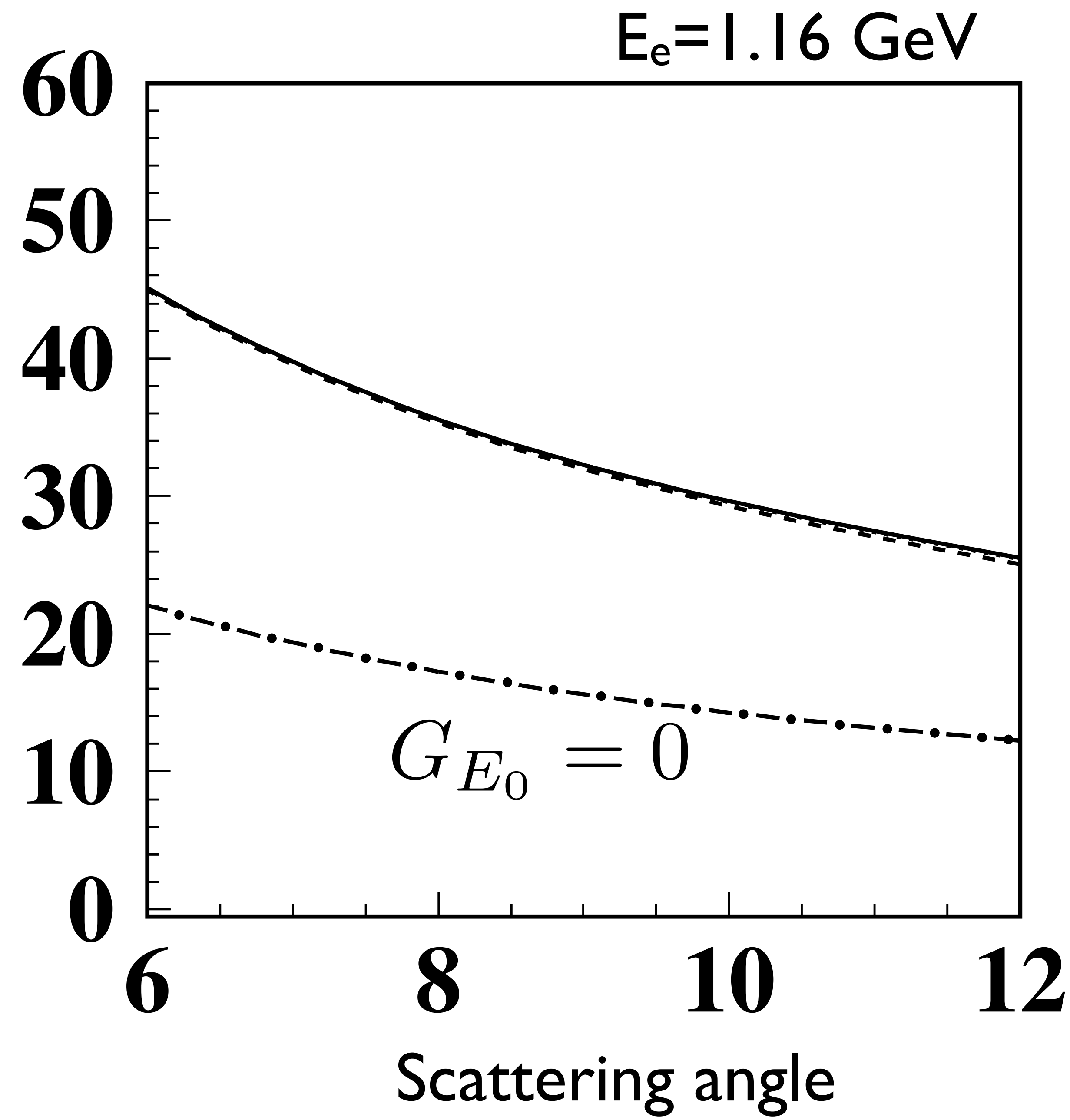


Δ intermediate more dominant at larger angles

B Pasquini, private communication

B_n asymmetry sensitivity to form factors



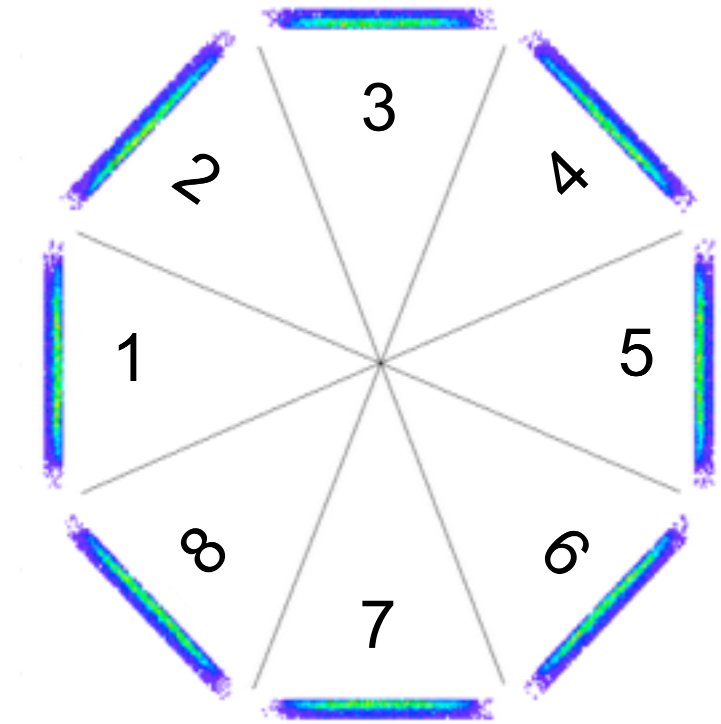


Backward angles dominated by magnetic form factor G_{M_1}

Forward angles dominated by charge form factor G_{E_0}

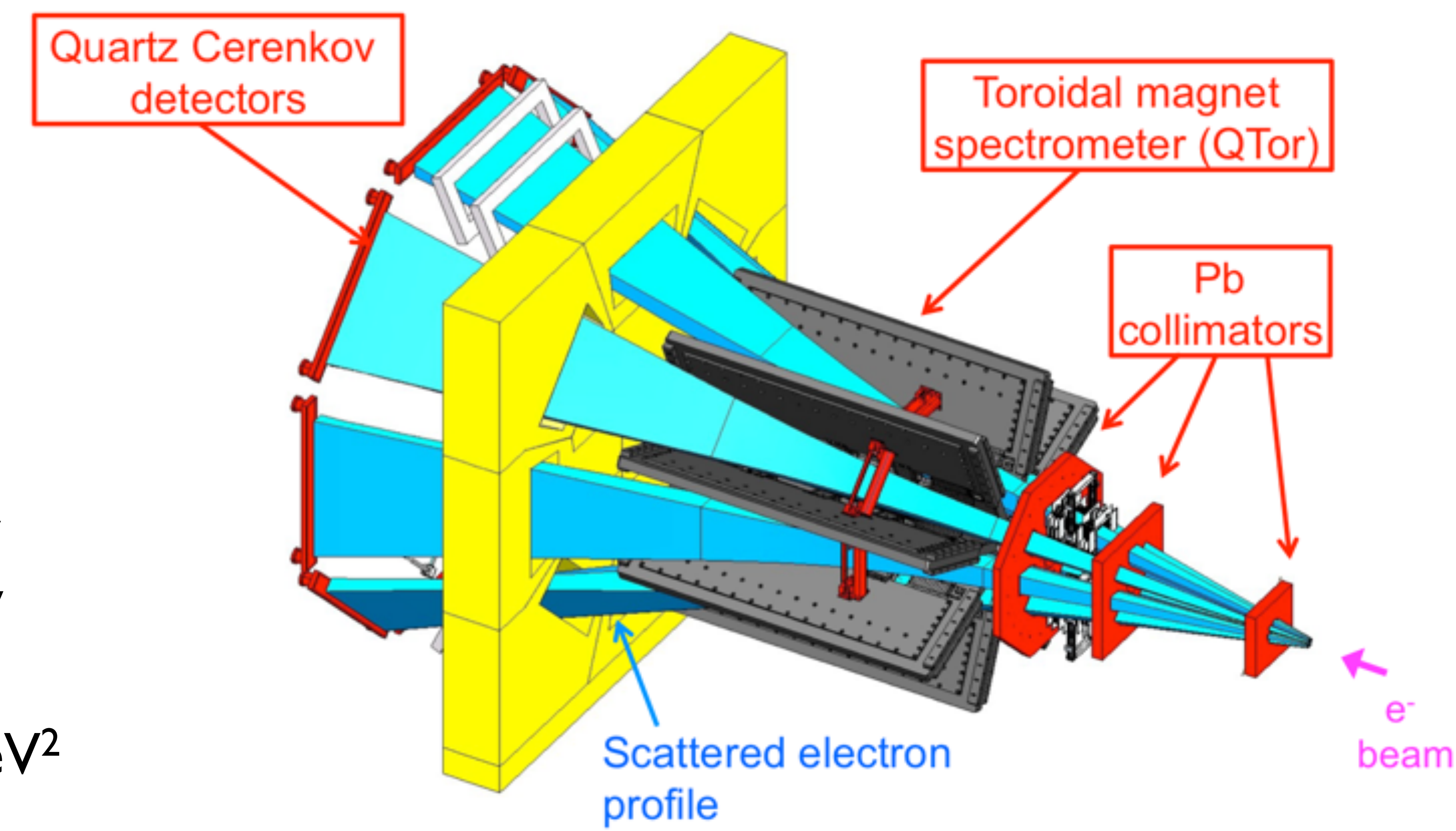
B Pasquini, private communication

Qweak Experiment



Designed to measure parity violation in ep scattering to order 10 parts per billion.

Measure transverse polarization asymmetry and inelastic asymmetry for background studies

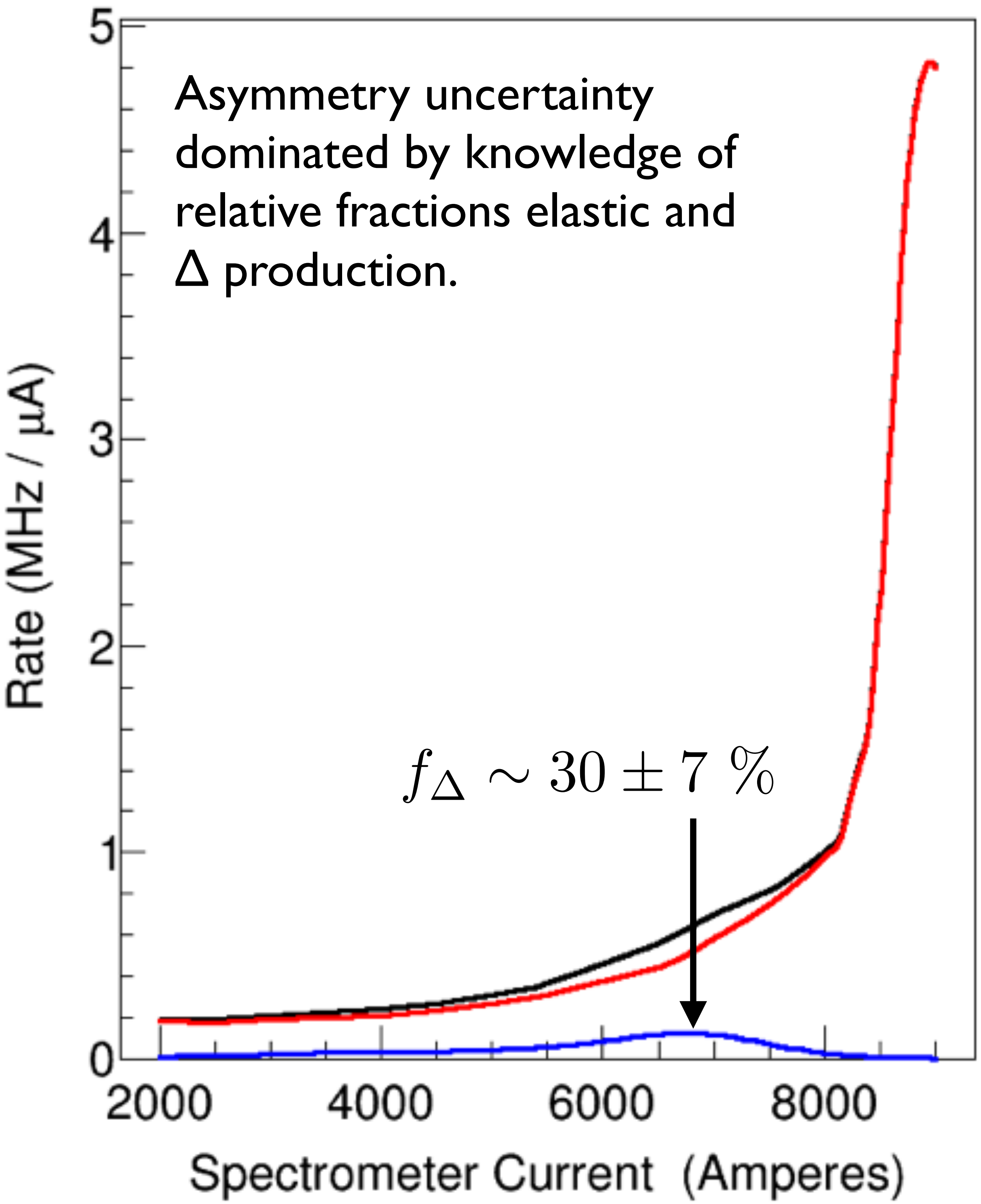


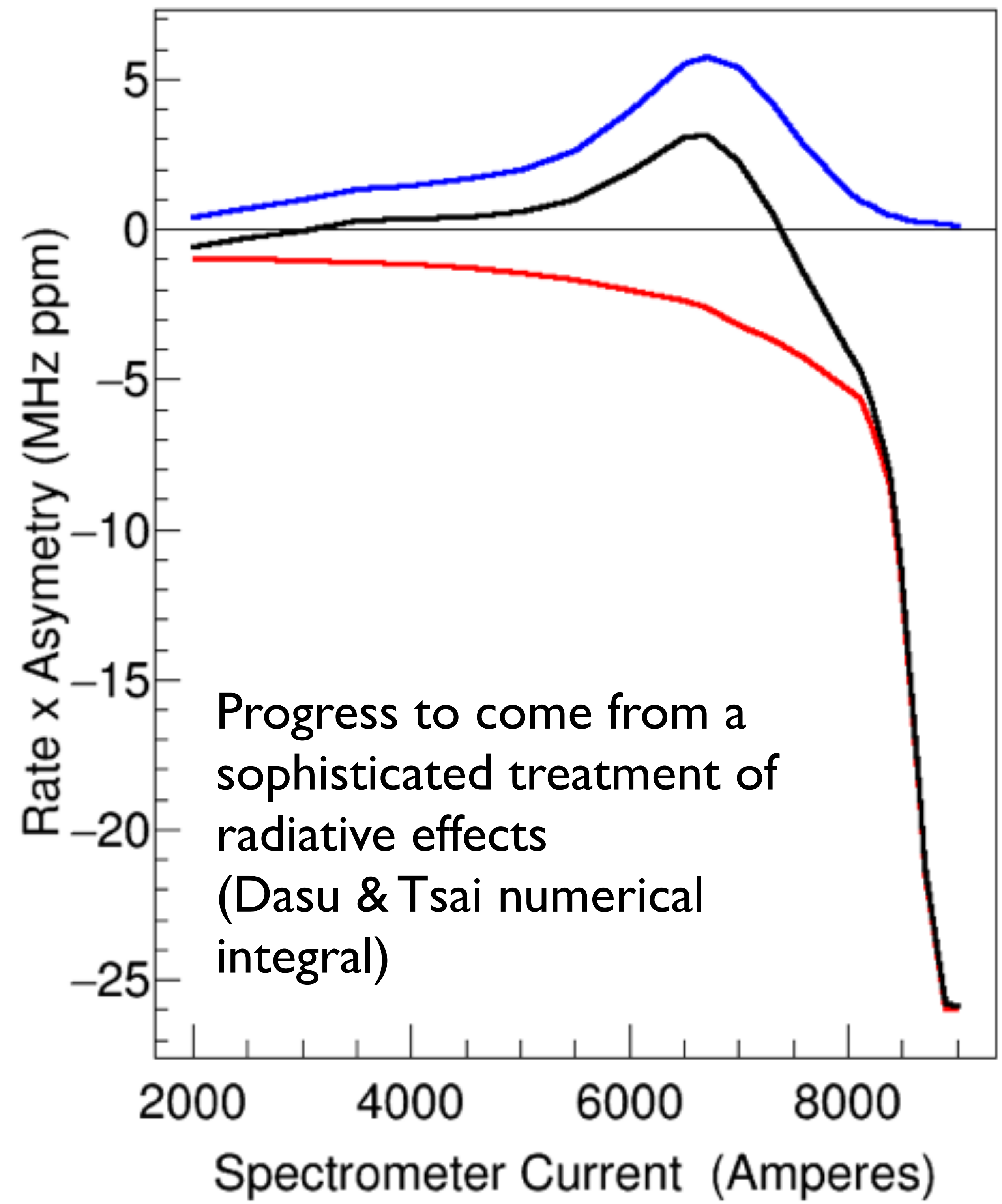
Δ kinematics

- $\langle E \rangle = 1.16$ GeV
- $\langle W \rangle \sim 1.2$ GeV
- $\langle \theta \rangle \sim 8.3°$
- $\langle Q^2 \rangle \sim 0.02$ GeV^2

Qweak Δ Production

Thick target, very forward kinematics — significant contribution from radiated elastic scattering



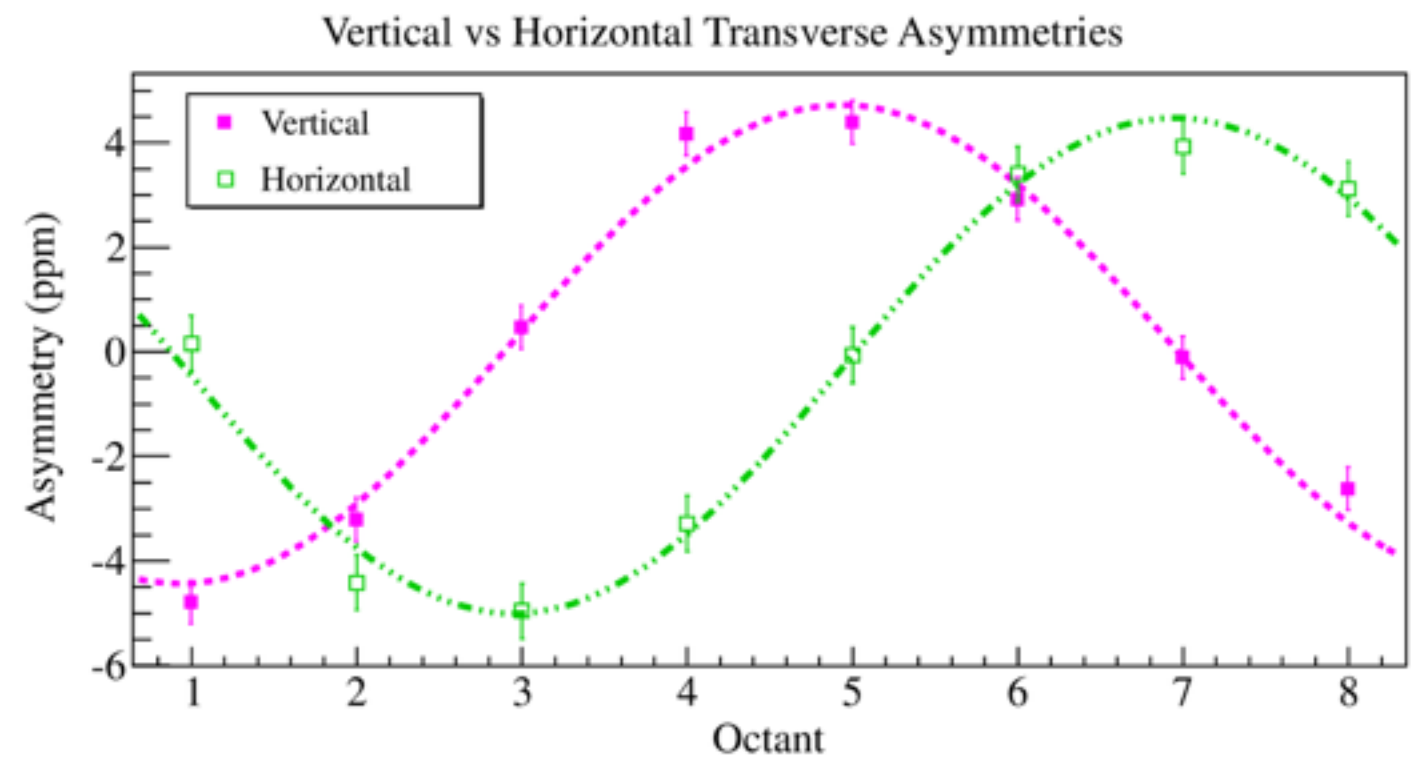


Measured Asymmetries

Measurement at elastic peak

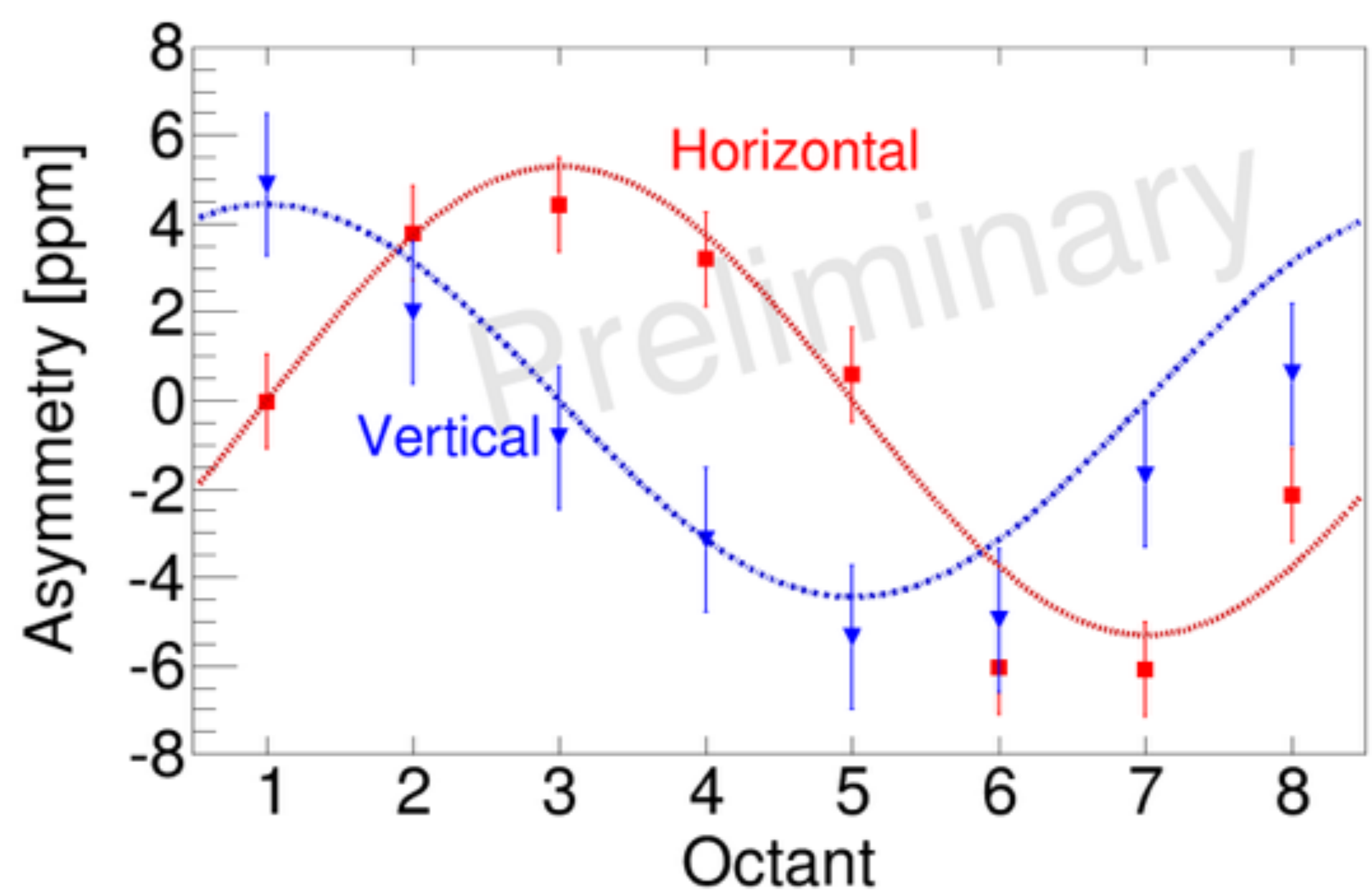
B_n = -5.30 ± 0.17 ppm

AIP Conf. Proc. 1560, 583 (2013) Waidyawansa

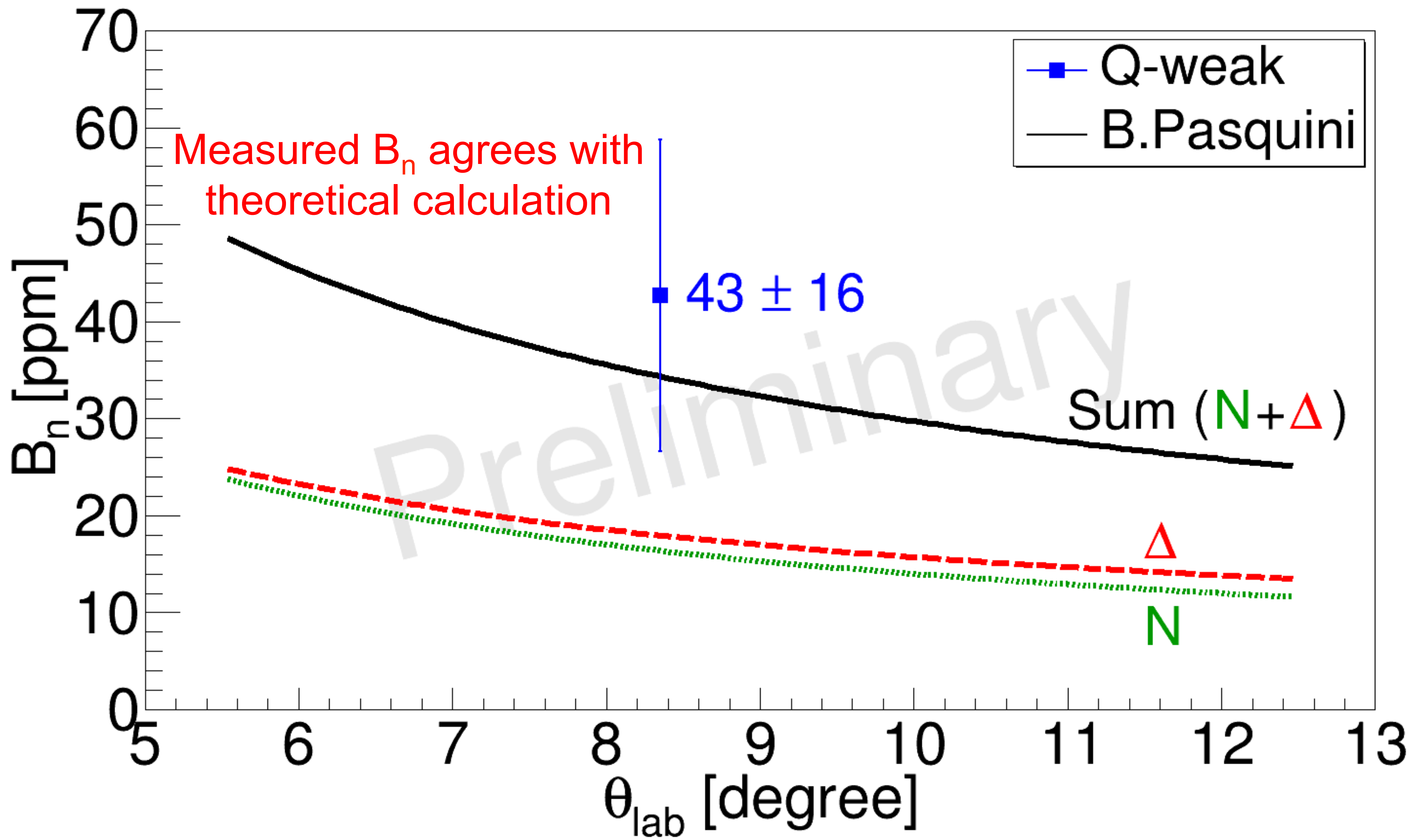


Measurement at Δ peak

B_{raw} = 5.1 ± 0.4 ppm



B_n Asymmetry Extraction



Expect a significant decrease in uncertainty as radiative effects are understood.
Similar available at 0.877 GeV.
More data is available at 1.60 GeV with different background fractions.

PVA4 at Mainz

PVA4 at Mainz

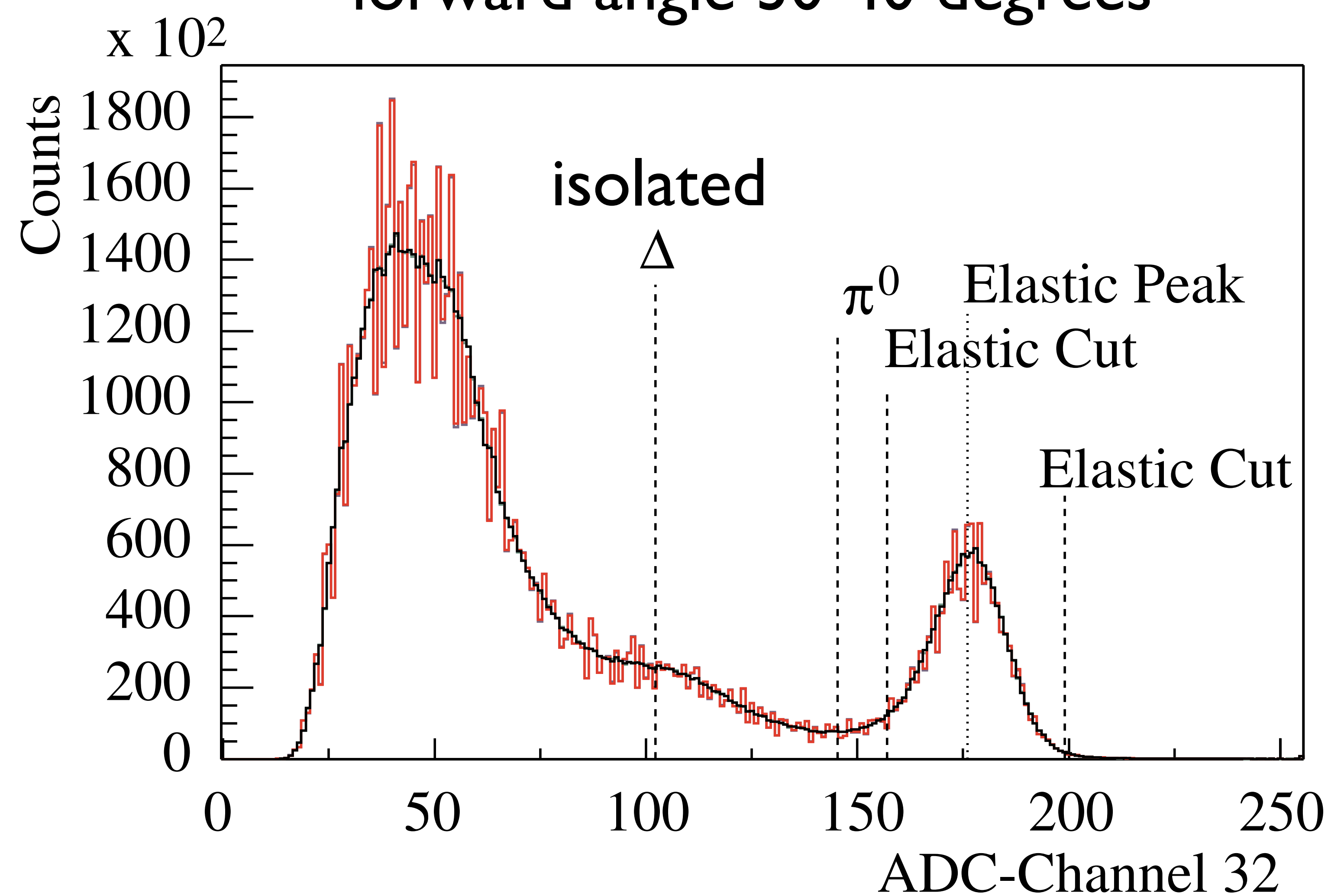
First results expected during 2015.

θ = 30-40 degrees
855 MeV: δA=2.1 ppm (stat)
1508 MeV: δA=5.1 ppm (stat)

Potential data at:
420 MeV, 510 MeV, 570 MeV
θ = 30-40 degrees

420 MeV, θ = 140-150 degrees

PVA4 raw spectrum, E=854 MeV
forward angle 30-40 degrees



PRL 93 (2004) 022002

Sebastian Baunack, private communication

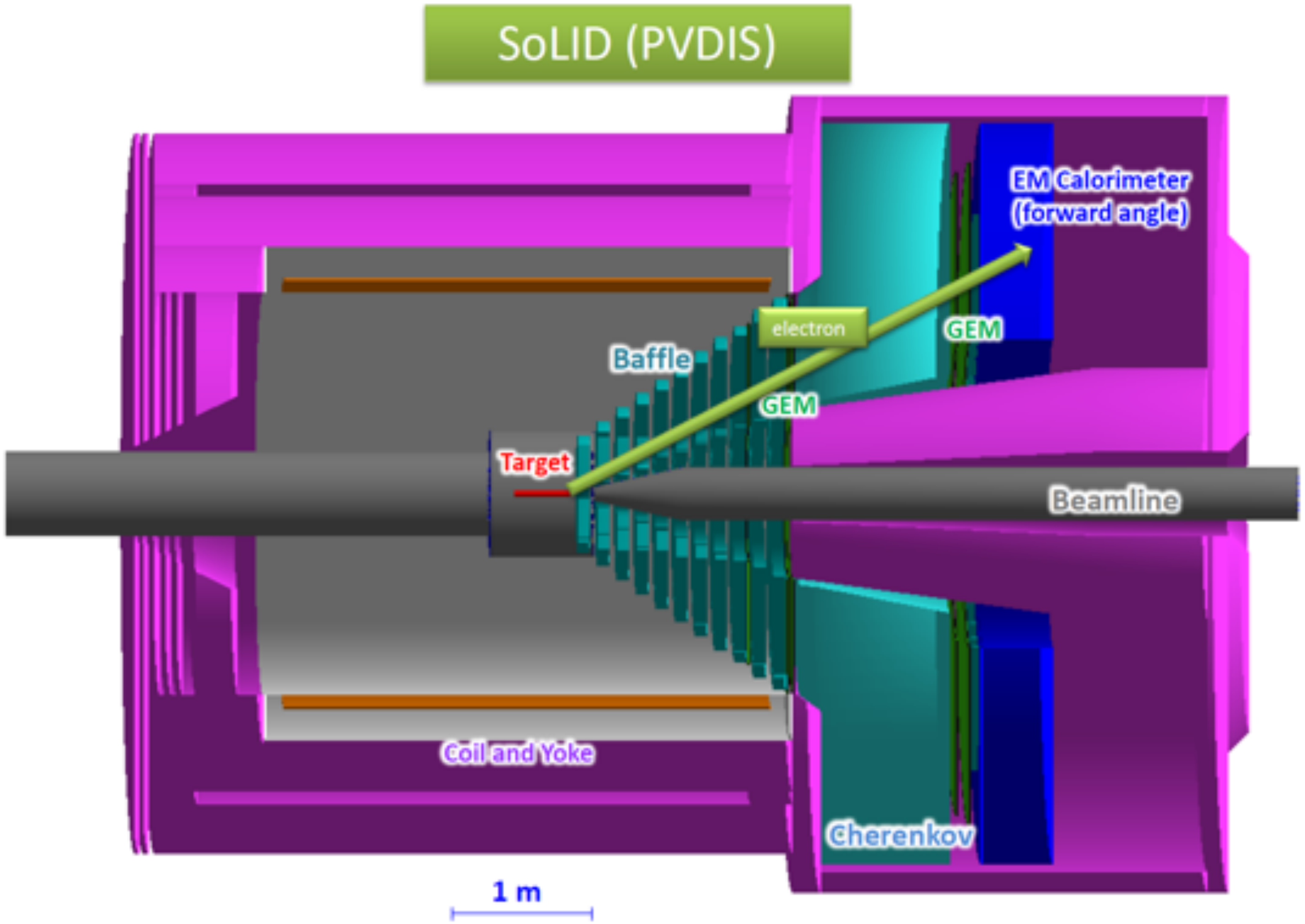
Future Measurements

- A1 at Mainz
- Cornell-BNL FFAG-ERL Test Accelerator
- Low Energy Recirculating Facility (LERF)
- SOLID at Jefferson Lab.

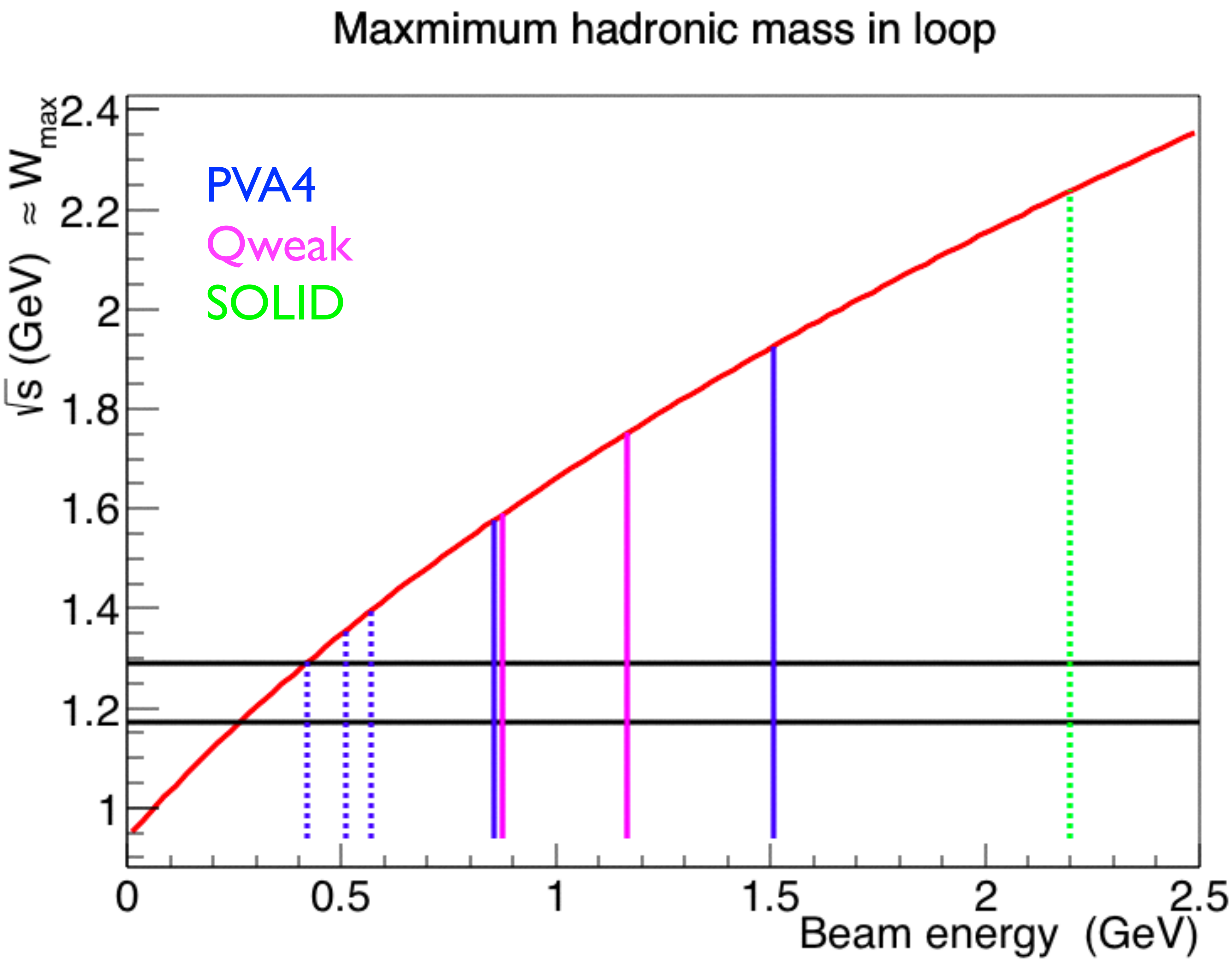
Intense Electron Beams Workshop,
Cornell University,
June 17-19 2015

20° - 35°, δp/p ~ 2%
some regions 10's of kHz/mm^2,
(Extremely high rate capabilities)

FOM (scattering rate, asymmetry and interpretability) increase to lower energy.



Summary of measurements



Summary

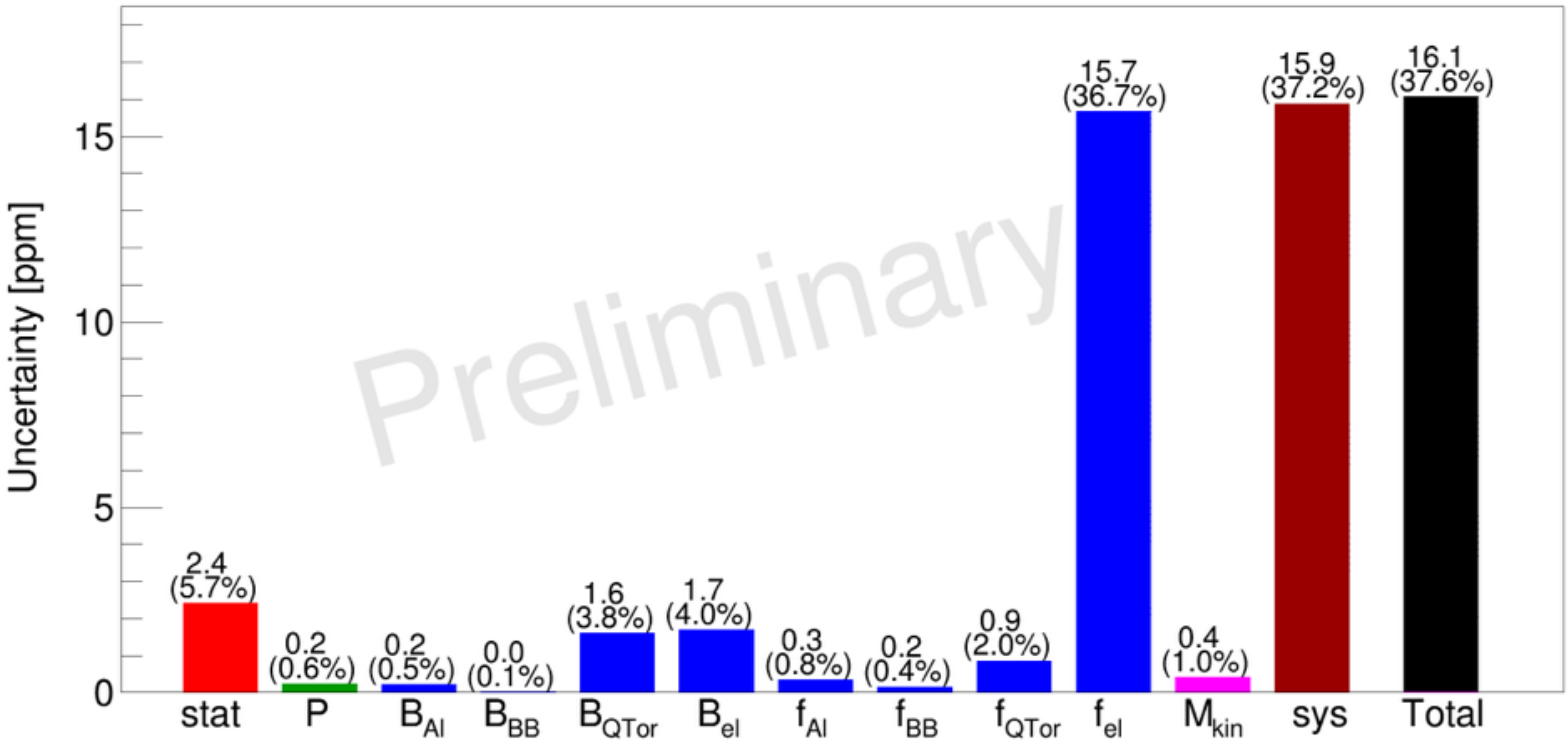
- The beam normal single spin asymmetry in Δ production is sensitive to the Δ elastic form-factors.
- Measurement of beam asymmetries is a robust, mature technique.
- Might allow for experimental testing of Δ elastic form-factor calculations.
- Theoretical studies needed to determine sensitivity.
- Future measurements may be possible using parity-violation apparatus.

Acknowledgements:

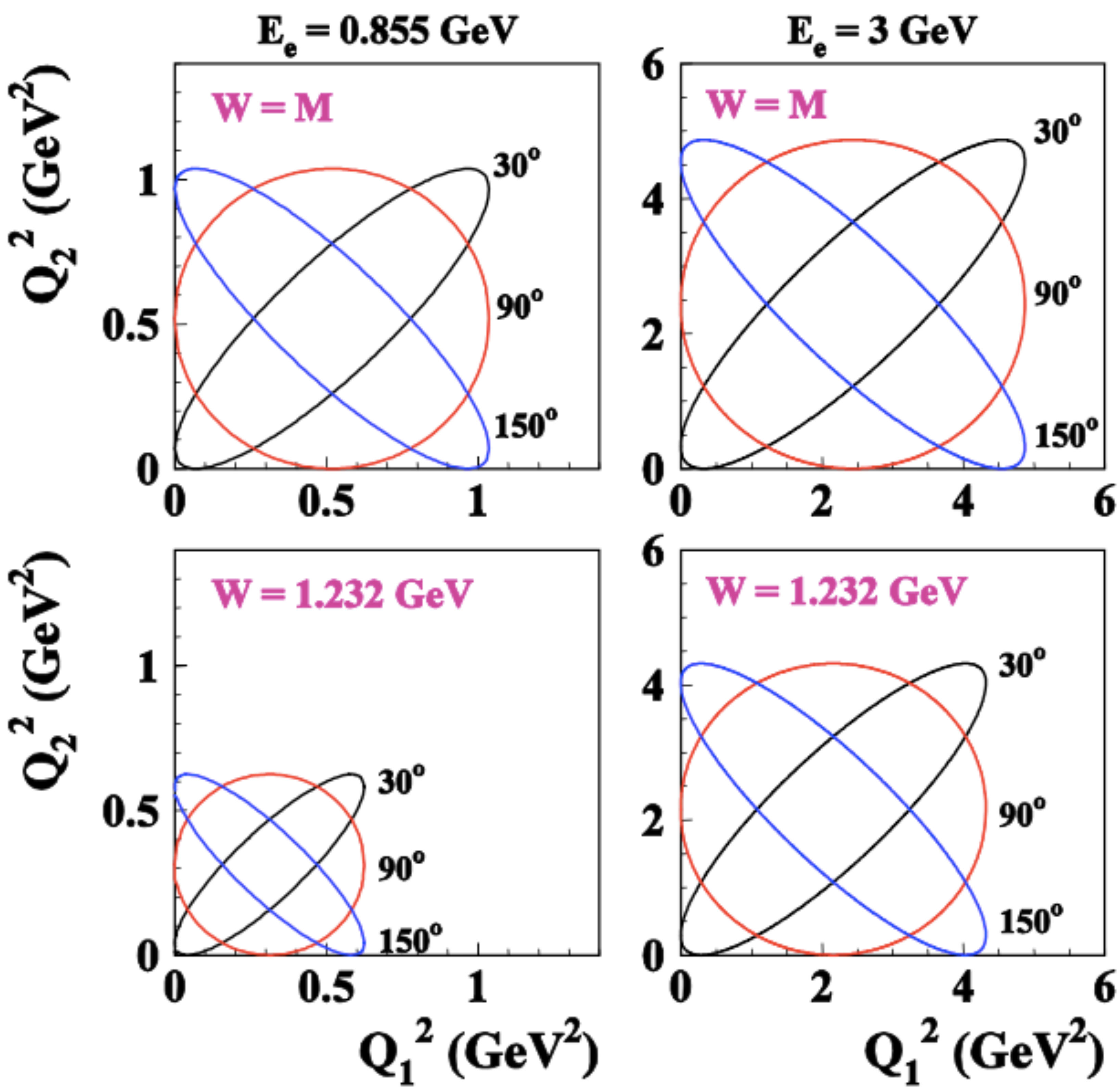
Barbara Pasquini, Carl Carlson, for helpful theoretical discussions.
Sebastian Baunack for Mainz data update.
The Qweak Collaboration.

Additional Material

Error Budget



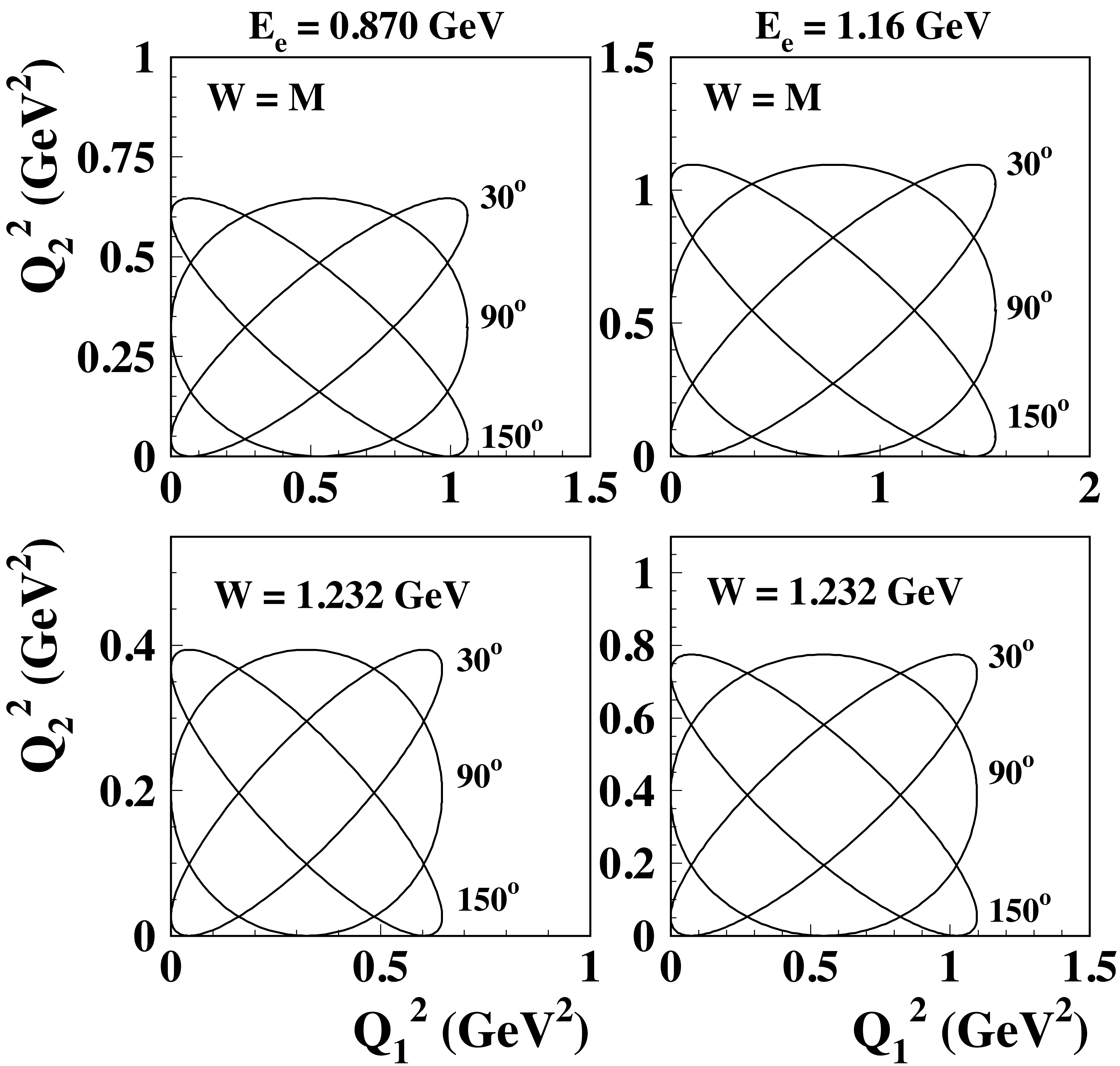
Photon momenta elastic scattering



Elastic contribution

Inelastic contribution

Photon momenta Δ production



Intermediate states do not interfere (1st order)